PHENIX Measurement of Parity-Violating Single Spin Asymmetry in W Production in p+p Collisions at 500 GeV

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Abstract. The flavor-separated polarized parton distribution functions for light quarks and anti-quarks in the proton can be studied in the production of W bosons in p+p collisions. The Ws are produced in processes like $u + \bar{d} \to W^+$ and $\bar{u} + d \to W^-$ and we observe the lepton (an electron or muon) from the decay channel $W^\pm \to l^\pm \nu$. The electron energy spectrum from W decays measured with an integrated luminosity of approximately 10 pb^{-1} will be shown, with a measurement of the electron single spin asymmetry in central rapidity.

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Over many years, the worldwide program of form factor measurements, inclusive deep-inelastic scattering and semi-inclusive deep-inelastic scattering experiments has made possible a definitive measurement of the polarized parton distribution functions (PDFs) of the u and d quarks. The recent global fit by de Florian, Sassot, Stratmann and Vogelsang (see Reference [1] and experimental references therein) shows a clear determination of the polarized PDFs $\Delta u(x)$ and $\Delta d(x)$. The polarized PDF for gluons, $\Delta g(x)$ has been greatly constrained by the recent measurements in $\vec{p}\vec{p}$ collisions at RHIC, but considerable uncertainties remain in the low-x region. The polarized PDFs for the sea quarks ($\Delta \bar{u}$, $\Delta \bar{d}$, Δs, and $\Delta \bar{s}$) remain relatively poorly determined, on the other hand.

The PHENIX Experiment at the Relativistic Heavy Ion Collider (RHIC) in Brookhaven National Laboratory is measuring parity-violating longitudinal single spin asymmetries in W production in $\vec{p}\vec{p}$ collisions that are sensitive to the light quark sea contribution to the proton spin. These asymmetries arise due to the fixed-helicity couplings in the production of the W, i.e. $u_L \bar{d}_R \to W^+$ and $d_L \bar{u}_R \to W^-$. The W may then be observed via its leptonic decay $W^\pm \to l^\pm \nu$ which produces a high-p_T lepton which is detected. The single-spin asymmetry in the number of observed leptons is [1, 2]

$$A_L^{l^+} = \frac{\Delta \bar{d}(x_1) u(x_2)(1+\cos\theta)^2 - \Delta u(x_1)\bar{d}(x_2)(1-\cos\theta)^2}{\bar{d}(x_1) u(x_2)(1+\cos\theta)^2 + u(x_1)\bar{d}(x_2)(1-\cos\theta)^2}$$

$$A_L^{l^-} = \frac{\Delta \bar{u}(x_1) d(x_2)(1-\cos\theta)^2 - \Delta d(x_1)\bar{u}(x_2)(1+\cos\theta)^2}{\bar{u}(x_1) d(x_2)(1-\cos\theta)^2 + d(x_1)\bar{u}(x_2)(1+\cos\theta)^2}$$

where θ is the lepton decay angle in the partonic center-of-mass system, and $x_{1,2} \equiv (Q/\sqrt{s})e^{\pm y_W}$. In certain kinematic limits, this asymmetry can have a very simple interpretation; for negative leptons detected at large forward (backward) rapidity, the asymmetry $A_L^{l^-}$ is very nearly equal to $\Delta d/d$ ($\Delta \bar{u}/\bar{u}$). In general, the measurement provides a

linear combination of polarized parton distributions functions which must be combined with other measurements to provide a flavor separation.

In the 2009 Run at RHIC there were polarized pp collisions at $\sqrt{s} = 500$ GeV for physics for the first time. Over a four week period, concurrent machine development and physics data-taking permitted significant improvements in delivered luminosity, an in-depth study of polarization transmission during the energy ramp up to $\sqrt{s} = 500$ GeV, and a first look at W production as a tool for studying the proton spin. The integrated luminosity at PHENIX, including the effect of a cut on the longitudinal distribution of collision vertices, was 8.6 pb^{-1}. The average polarization of the beams was 0.39 ± 0.04. The beam polarization was monitored by a combination of high-rate proton-carbon scattering events from an unpolarized carbon target that provide a relative measurement of proton polarization during the run, low-rate proton-proton scattering events from a polarized hydrogen gas jet that provide an absolute calibration of the beam polarization, and a local polarimeter at PHENIX that makes use of the transverse single spin asymmetry of forward neutrons observed in the zero-degree calorimeter (ZDC)[1].

During the 2009 Run, only the central arms of PHENIX were prepared to observe the very low rate of very high p_T leptons that arise from W decay. (In future runs at 500 GeV, after ongoing upgrades, also the PHENIX muon detector arms at forward and backward rapidity will be able to observe muons from W decay with acceptable backgrounds.) The PHENIX central arms[2] cover $|\eta| < 0.35$ in rapidity, and the two arms cover a total of π radians in azimuth. For the purposes of observing these high-p_T electrons and positrons, PHENIX employed a drift chamber and pad chambers to measure the deflection of the trajectory of the particle in the PHENIX central magnet, and an electromagnetic calorimeter (of both PbGl and PbSc construction) to measure the energy of the particle. A variety of cuts (matching particle tracks to calorimeter clusters, a timing cut to eliminate cosmic ray events, and an E/p cut to eliminate hadrons) reduced the backgrounds from QCD processes (mostly pion production) to a level where a Jacobian signal in the electron and positron p_T spectra could be seen; see solid red histogram in Figure 1. For the purposes of determining the longitudinal single-spin asymmetry, an additional isolation cut was made – we required that that total amount of additional energy and momenta in a cone of radius 0.5 in η and ϕ around the identified cluster was less than 2 GeV. This last cut reduces the background in the signal region ($30 < p_T < 50$ GeV/c) by a factor of about 4; see dashed blue histogram in Figure 1. We are not able to exclude events due to Z production and decay from our data sample; the number of Z events expected is small, about 7% of the W^+ sample and about 30% of the W^- sample.

The measured experimental single-spin asymmetry was determined from the experimental data by combining the number of high-p_T leptons observed when one of the beams had positive (right-handed) helicity, N^+, with the number observed when one of

[1] See the contribution by Sebastian White.
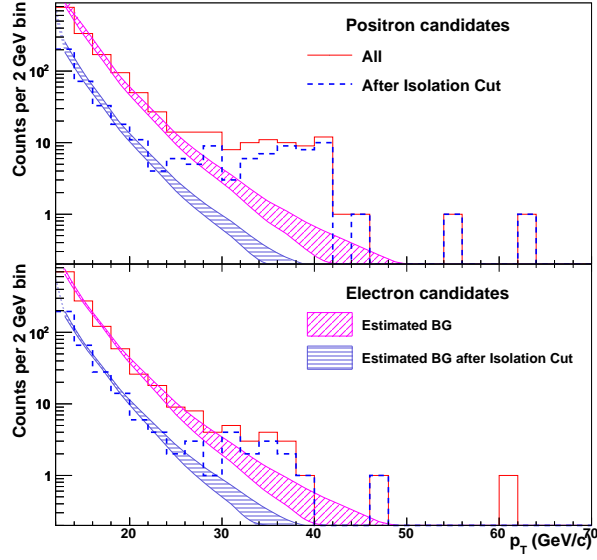[2] For PHENIX overview, see the contribution by Murad Sarsour.

FIGURE 1. The spectra of positive (upper panel) and negative (lower panel) candidates before (solid histogram) and after (dashed histogram) an isolation cut. The estimated background bands are also shown. The computation of the background before the isolation cut contains contributions primarily from photon conversions before the drift chamber and from charged hadrons; this is described in Ref [4]. The background band after the isolation cut is computed by scaling the background before the isolation cut by the isolation cut efficiency measured in the background region ($12 < p_T < 20$ GeV/c).

the beams had negative (left-handed) helicity, N^-:

$$\varepsilon_L = \frac{N^+ - R \cdot N^-}{N^+ + R \cdot N^-}$$

where R is the relative integrated luminosity of the positive to the negative helicity collisions, L^+/L^-. The physical parity-violating single-spin asymmetry was then determined using the polarization P of the beams and correcting for the dilution D of the asymmetry due to background events:

$$A_L = \frac{\varepsilon_L \cdot D}{P}.$$

In order to maximize the usefulness of the rather limited statistics in this initial measurement (42 positron events and 13 electron events) a likelihood function was used to determine confidence intervals for A_L; this allowed us to make use of the constraint that A_L must lie in the range -1 to $+1$. The results of this analysis are shown in Table 1. Even in this first measurement, the results are striking. This is the first observation of parity-violation in the production of W bosons; $A_L^{e^+}$ is non-zero at 95% confidence level. In Figure 2 these results are shown in comparison to predictions [3] of these asymmetries based on current fits of polarized PDFs. These results have been submitted for publication by the PHENIX collaboration [4]. The STAR collaboration at RHIC has made a measurement of W production as well [5].

To summarize, PHENIX has observed a non-zero parity-violating asymmetry in W production in polarized pp collisions at 500 GeV. These asymmetries are sensitive to
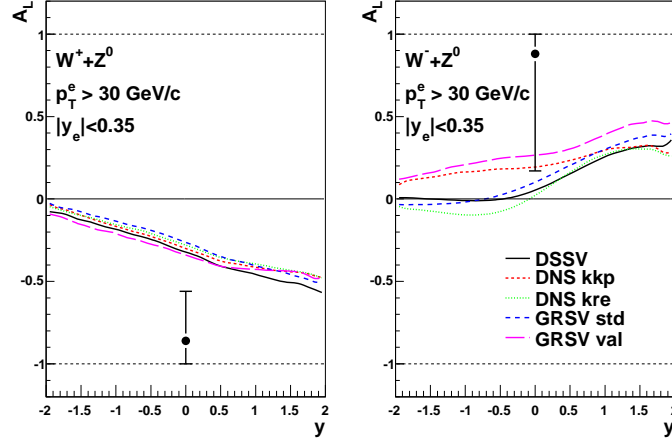
FIGURE 2. Longitudinal single spin asymmetries for electrons and positrons from W and Z decays. The error bars represent 68% CL. The theoretical curves are calculated using different polarized PDFs [3].

TABLE 1. Parity-violating single-spin asymmetry A_L.

Sample	ε_L	$A_L^e(W+Z)$	68% CL	95 % CL
Bkgrnd +	-0.015 ± 0.04			
Signal +	-0.31 ± 0.10	-0.86	$[-1, -0.56]$	$[-1, -0.16]$
Bkgrnd −	-0.025 ± 0.04			
Signal −	0.29 ± 0.20	$+0.88$	$[0.17, 1]$	$[-0.60, 1]$

the contribution of the light quark sea to the spin of the nucleon. In the next few years we look forward to the collection of 100-200 pb^{-1} of additional data on this process and providing strong constraints in the determination of $\Delta\bar{u}(x)$ and $\Delta\bar{d}(x)$.

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